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Drainage System of Tegalsari Polder for Handling Flood and Tide in Tegal City Indonesia

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Drainage System of Tegalsari Polder for Handling Flood and Tide in Tegal City Indonesia

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Abstract: Although in 2019 the local government of Tegal city Indonesia had constructed a retention basin at drainage system of Siwatu, Tegal Barat, Tegal city with a catchment area of 226 ha, the areas around the system still experienced flood and inundation. This study belonged to a descriptive qualitative research aimed to evaluate the performances of Siwatu drainage system and Tegalsari retention basin. Data of the study included field data and technical data from institutions. Based on the 15-year rainfall data (2014 – 2018) from Pemali - Comal PSDA Office, Central Java Province, Indonesia, the statistical parameters of Cs: 0.0027, Ck: 1.904, Sd: 15.91, Cv: 0.144 were obtained and so Gumbel method distribution was applied in the study, the return period rainfall of 10 years was 138 mm, the flood discharge for Qr.10 years was 9.63 m^3/sec., the addition of long storage was 8x2,50x500 m, and the combination of pump addition was of 1 m^3/sec. with the long storage of 8x2.00x500 m. By implementing one of the alternative choices, either flood or inundation could be resolved.

1. Introduction

The city of Tegal is one of the cities in Indonesia directly adjacent to the Java Sea. The geographical position of the City is between 109˚08'- 109˚10' east longitude and 6˚50'- 6˚53' south latitude. Flooding and inundation are problems which commonly occur due to drainage channel condition which are not capable of receiving rainfall; the city location which is close to the coastal area; very less slope of land; changes in function from water catchment areas into settlements; and other land functions [1].

Kraton Village, Pekauman Village, and Tegalsari Village in the district of Tegal Barat, Tegal City are the areas subject to flooding and inundation. In 2019, the local government of the city has built a retention basin in Siwatu Drainage System. This basin has a catchment area of 226 ha, with an area of retention basin of 1 ha, depth of 4.50 m, pumping capacity of 4 x 1,000 lps. Through the polder system, rainwater is channeled through Siwatu River to Tegalsari Retention basin and then pumped further into Sibelis River. Inundation with the height of 20 cm to 80 cm still occurs in the housing complexes of Rambutan Raya and Abdi Negara and the school area of SMA 2, Tegal city, mainly when it was raining heavily for more than 1 hour, even though 4 pumps have been operated.

This study aims to find out the best solution to overcome flooding and inundation through maximizing the function of Tegalsari polder system and maximizing the pumping machine operation management, including setting the time to start and to stop the pumping machines and the addition of the retention basin or pumping machines. With these endeavors, the problems of flooding and inundation are expected to resolve. The following figure 1 is the site map of Siwatu Drainage System in Tegal City.

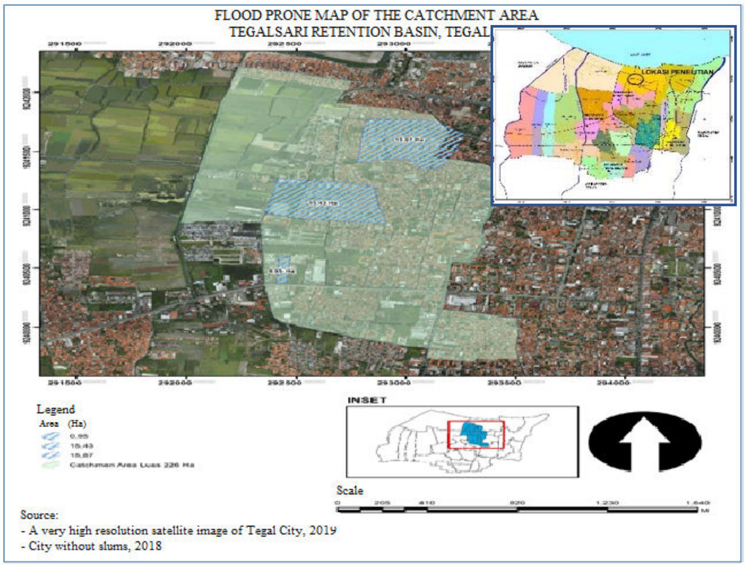

Figure 1. Site Map.

2. Literature Review

2.1. Polder System

Polder system is an area where the water level is lower than the water level at discharge estuary. Drainage cannot be carried out naturally or by gravity, therefore, a pump system is required. To prevent runoff water from other areas into the polder system, the land bordering the river needs to be elevated. The following are parts of the polder system: (1) Polder embankment, (2) Drainage system (3) retention basin and pumping station and (4) receiving water body [2].

In addition to controlling floods, the polder system can also make flood-prone areas more controllable, land can be utilized according to plans. Likewise, it provides wider participation for the community in managing the environment to ensure its sustainability, especially the conservation of water resource [3].

2.2. Retention Basin

Retention basins function when rainfall is high and the capacity of the drainage channel cannot accommodate the volume of water. Therefore, a water volume temporary storage is needed. When the water volume returns to normal, the water will gradually be flowed out of the polder system. The drainage can be carried out by gravity if the slope of the channel and the water level meet the requirements, but if it cannot, the water can be channeled through the pumping system. Calculation of the basin must consider the river flood hydrograph, elevation of the existing environmental conditions. The basin size needs to regard maximum discharge which comes into the polder system, if the existing size cannot accommodate, the minimum size is taken and the capacity of the pump is increased [4].

Polder systems with retention basin must be able not only to receive water from the farthest and lowest drainage channels in the retention basin service system, but must also be able to control the influence of tides. The sluice gate in the estuary is installed as a system to control tidal water, draining and controlling waste carried by drainage flow. Garbage filters are also installed that the water entering the pumping room does not carry materials which may endanger the pumping machine when it is operated [5].

2.3. Drainage

Drainage is an effort to control water excess from rainwater, seepage water, and irrigation water within the area of an irrigation network, with the aim of keeping the land productive [2]. While the urban drainage system is a unified technical and non-technical system of drainage infrastructure in regulating and managing surface water so as not to interfere with community activities [6]. Water from the rain will be streamed through drainage channels to the final disposal or temporary storage in the form of a retention basin and then discharged to the receiving water body either through the gravity system or the pumping system.

2.4. Optimization

Optimization is the action of making the best or most effective use of a situation or resource [7]. It is also a way to find best solution, not only in term of profit and minimizing operational costs, but also optimizing and improving methods [8].

Optimization of Tegalsari retention basin in Tegal city referred to the basin operation, which included a polder system with a holding pool of 1 ha, a depth of 4.5 m, and with 4 pumping machines with a capacity of 1000 *lps* aimed to reduce flooding and inundation occurring in Siwatu Drainage System, district of Tegal barat, Tegal City. If the operation of the existing system still could not overcome the problem, the optimization needed to carry out through other methods, such as optimizing the working hours of the pumping machines (setting the best time to start and to stop the pumping) [5], adding the water basin using the existing river channels, procuring more pumping machines, and combining between the pumps addition and pools. With these methods, it was expected flooding and inundation problems were solved.

Stages to optimize the Retention basin were made by determining the capacity of the basin, pumping capacity and drainage System of Siwatu in term of receiving the flow discharge entering the polder system [9]. Hydrological analysis was carried out to calculate the maximum amount of rainfall and flood discharge.

- Frequency Analysis
  Probability distribution or frequency analysis was used to determine the frequency magnitude of the extreme events took place using the probability distribution. The statistical values used were: standard deviation (s), average value ($\bar{x}$), kurtosis coefficient (C_k), sloping coefficient (C_s) [2]. Determination of frequency analysis was done by matching the statistical value with each type of distribution. Frequency distribution methods often applied were Normal Distribution, Log Normal Distribution, Pearson Type III Log Distribution, and Gumbel Distribution [2].

- Rainfall Intensity
  Rainfall intensity was either height or depth of rainwater per unit time [2]. To analyze the rainfall intensity, Mononobe method with the following formula was used:

$$I_t = \frac{R_{24}}{24}\left[\frac{24}{tc}\right]^{\frac{2}{3}} \tag{1}$$

  Where: I_t= rainfall intensity for rainfall duration t (mm/hour), t = duration of rainfall (hour), R_{24}=rainfall maximum for 24 hours (mm)

- Rational Method
  For small catchment areas, estimated discharge could be calculated using the Rational Method. Catchment area was regarded small if the frequency of rain was uniform in term of space and time. Duration of the rain generally exceeded the concentration time and the catchment area was

less than 2.5 km^2 [10]. The rational method was based on the following equation:

$$Q = 0,278. C . I . A \tag{2}$$

Where : Q : peak discharge (m^3/sec.), I : rain intensity (mm/hour) A : catchment area (km^2), C : runoff coefficient, runoff water into the ground (to an area that was not saturated with water) [11]. C value used for Tegalsari Retention basin was C: 0.55, as the research sites were in residential areas.

- Concentration Time

  Concentration time was the time required for rainwater to flow from the farthest point to the discharge in the catchment area (control point) after the soil became saturated and the small depressions were filled. Below is the time of concentration with the Kirpich equation [2]:

$$t_c = 0,0195. L^{0,77} S^{-0,385} \tag{3}$$

  Where: t_c: concentration time, L: channel length (m) S : channel slope

- Channel

  To determine dimensions of the channel, the water flow conditions were assumed to be in steady uniform flow conditions. Below is Manning formula to determine dimension of channel [2].

$$Q = V. A \tag{4}$$

$$V = \frac{1}{n}\, x\, R^{2/3}\, x\, I^{1/2} \tag{5}$$

  Where: Q: flood discharge (m^3/sec.), A: catchment area (km^2), : V: velocity (m/sec.), R : Hydraulic spokes (m), I : channel slope.

- Retention Basin and Pump capacity

  To determine the area of the basin and the pump capacity, basin simulation was used. For time interval t, flood retention basin equation was written as follows [12] :

$$Q = \frac{Q_{flood1} + Q_{flood2}}{2} x\, t - \frac{P_1 + P_2}{2} x\, t = S_1 + S_2 \tag{6}$$

  Where: Q: flood discharge (m^3/sec.), P : Pump (m^3/sec.),: t: time interval (hour), S : retention basin (m^3).

3. Research Method

This was a qualitative descriptive study carried out in Siwatu Drainage System of Tegalsari Retention basin, Tegal City, Indonesia. Secondary data for the study were relevant literatures, and technical data such as hydrological data and climatological data at the research location collected from related agencies. While the primary data were obtained directly from the site of the study, Siwatu Drainage System and Tegalsari Retention Basin in Tegalsari Village, Tegal City. For benefit of the study, the primary and secondary data were combined and processed for analysis of flood discharge, and conducting simulation of the retention basin, the pumping capacity and the pumping operation.

4. Result and Discussion

Hydrological data were in the form of maximum daily rainfall data within 15 years (2004 to 2018) collected from Pemali Comal PSDA Office of Central Java Province, Indonesia. See figure 2 for detail.

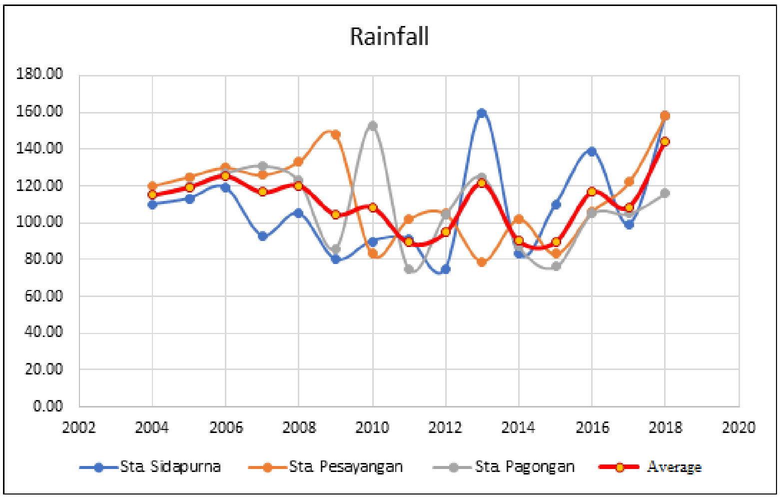

Figure 2. Rainfall Data.

Using the algebraic mean method, the average rainfall of 110.316 mm was generated. Below were the statistical parameter values as a result in the calculation: (1) standard deviation value (*Sd*): 15.911, (2) kurtosis coefficient (*Ck*): 1.904 and (3) slope coefficient (*Cs*): -0.0027, thus, Gumbel distribution method was selected. The Fittest test conducted using critical deviation limit Smirnov-Kolmogorov ($D_{0critic}$) of 0.340 had generated (D_{max}) of 0.094. However, it was still under $D_{0critic}$. From the calculation of the critical chi-square value of 24.00 as a result in the chi-square test result, the value of 1.00 was obtained. This value was smaller than the chi-square critic. Based on the goodness of fittest test, the Gumbel method was accepted. With the rainfall Gumbel distribution method for Qr.10 years, the value was 138.00 mm.

If the catchment area was below 500 ha, the calculation of the estimated flood discharge was made using the Rational Method [10] and based on the *Qr*.10 years [6], *C* value: 0.55, considering that it was a residential area, the concentration time was determined based on the length and the slope of river, while the drainage service area was determined based on the area served. See figure 3 for drainage system and flow direction of Siwatu. The peak flood discharge of each channel was different, the bigger the estuary, the bigger the discharge. The results of the calculation of the total discharge in each drainage channel are shown in table 1 below.

Figure 3. Drainage Flow Pattern of Siwatu.

Table 1. Existing Channel Capacity as compared to Estimated Discharge.

No.	Channel name	Channel type	Existing channel capacity (m^3/sec.)	Estimated discharge (Q10) (m^3/sec.)
1	Channel AlFatah	Secondary	0,361	0,493
2	Channel Sibuntu	Secondary	1,142	2,039
3	Channel Sawo Barat	Secondary	0,145	1,063
4	Channel of RT 06, RW 03, Village of Tegalsari	Secondary	0,055	0,422
5	Channel of RT 05 RW 03 Village of Tegalsari	Secondary	0,052	0,437
6	Channel of RT 04, RW 03, Village of Tegalsari	Secondary	0,059	0,508
7	Channel of RT 03, RW 03, Village of Tegalsari	Secondary	0,067	0,679
8	Channel of Rusunawa baru	Secondary	0,064	0,626
9	Channel of Jl. Rambutan Raya	Secondary	0,047	0,226
10	Channel of Jl. Rambutan 13	Secondary	0,158	1,010
11	Channel of Jl. Sawo	Secondary	0,209	1,256
12	Channel of Cinde	Secondary	0,697	0,659
13	Channel of Cindekirana-Cucut	Secondary	0,166	0,461
14	Channel of Bawal Baru	Secondary	0,040	1,056
15	Channel of Jl. Bawal	Secondary	0,089	0,342
16	Channel of Siwatu	Primary	4,541	9,630

Based on table 1, drainage of Siwatu was not capable of handling the estimated discharge. Therefore, channel normalization, channel widening or retention basin construction with the pumping system disposal could be implemented. It depended on the cost and the land condition in the site of the study [13]. In the calculation of the existing retention basin with an area of 1 ha, depth of 4.50 m and pumping machine of 4 m^3/sec., the accommodated volume was 37000 m^3. This was smaller than the volume of estimated retention basin of 46188 m^3. Based on the insufficient discharge capacity of drainage and retention basin, the existing polder system needed for simulation using several methods [14].

Based on the existing condition of Tegalsari retention basin, elevation of the basin embankment was +2.50, the estimated flood surface elevation was +1.700, the basin base elevation was -2.00, the inlet base elevation was +0.608, the normal water level of Siwatu river was +1.223. The pumping machines started operation at the elevation of +1.400. See figure 4 for the existing condition.

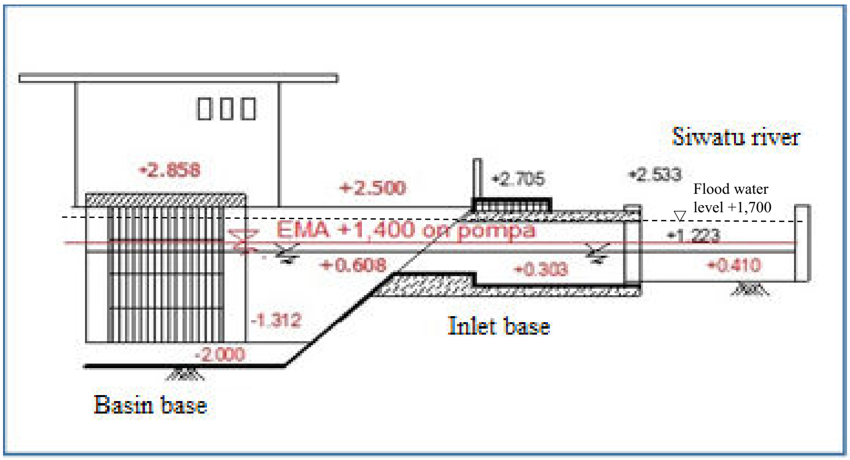

Figure 4. The existing condition of the Tegalsari Retention Basin.

In the design of *Q*.10-year discharge with the operation of all 4 m^3/sec. pumping machines, the machines were operated at the water elevation of +1.400, when there was no flood at the first 20^{th} minutes. Flood happened after the 30^{th} minutes to the 180^{th} minutes when the water elevation exceeded the flood peak elevation of +1.700. Therefore, simulations were conducted at the retention basin of Tegalsari to resolve the problems:

4.1 Addition of pumping machines

By adding the pumping machines of 3 m^3/sec., the pumping capacity became 7 m^3/sec. Simulation result of the environmental condition showed that it was safe from flood. Pumping operation remained at the water elevation of +1.400, flood water elevation of +1.700. Water elevation in the retention basin was used as the operational pattern of each pump to streamline between the cost of pump maintenance and operation [5], see table 2 and figure 5 for detail.

Table 2. Simulation of Tegalsari retention basin pump addition.

Routing Time Hour	Minute	Q.10 Years m^3/sec	Existing Pump 4 m^3/sec	Volume IN (m^3)	Volume OUT (m^3)	Volume of Basin	Water Elevation	Environmental Conditions
0,00	0	0,00	0,00	0,00	0,00	0,00	1,562	Safe
0,08	5	86,66	1,00	25.996,76	300,00	25.696,76	1,181	Safe
0,17	10	54,59	2,00	32.753,87	1200,00	31.553,87	1,450	Safe
0,25	15	41,66	3,00	37.493,82	2700,00	34.793,82	1,599	Safe
0,33	20	34,39	4,00	41.267,28	4800,00	36.467,28	1,620	Safe
0,50	30	26,24	6,00	47.239,25	10800,00	36.439,25	1,674	Safe
1,00	60	16,53	7,00	59.517,72	25200,00	34.317,72	1,577	Safe
2,00	120	10,41	6,00	74.987,63	43200,00	31.787,63	1,461	Safe
3,00	180	7,95	5,00	85.839,41	54000,00	31.839,41	1,463	Safe
4,00	240	6,56	4,00	94.478,50	57600,00	36.878,50	1,694	Safe
5,00	300	5,65	4,00	101.773,88	72000,00	29.773,88	1,368	Safe
5,50	330	5,31	4,00	105.059,15	79200,00	25.859,15	1,188	Safe
6,00	360	5,01	4,00	108.150,88	86400,00	21.750,88	0,999	Safe

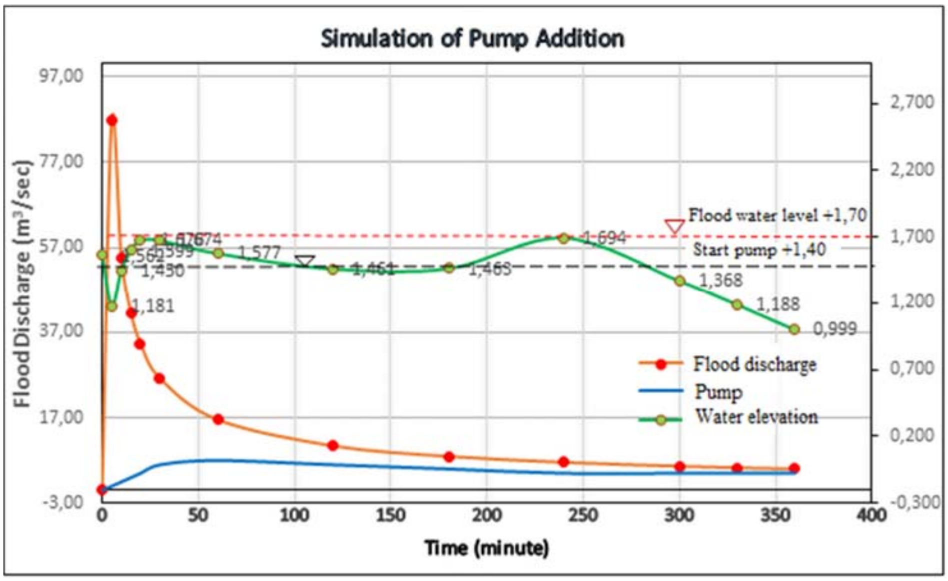

Figure 5. Graph of the existing simulation using pumping machine addition.

4.2 Addition of Retention Basin

An ideal size of retention basin in a polder system was at least 3% of the catchment area [3]. If the addition of pump capacity required high procurement and operational costs, other efforts were needed beside the pump addition such as utilizing Carrier Channels as a long-storage [15]. Through the same way, the existing condition was simulated by the addition of retention basin. The retention basin in the polder system of Tegalsari was made by utilizing Siwatu river as a long-storage. From the calculation result for *Q*.10-year period, a long-storage of Siwatu river with dimension of b.8.00 m h. 2.50 m p. 500 m was obtained, as the result, the total volume of the retention became 47000 m^3.

4.3 Combination between the addition of retention basin and the addition of pumps

Further to the additions of the pumping machines and the retention basin, simulation was also conducted to optimize the polder system of Tegalsari by combining between the additions of pumping machine and the long-storage as the replenishment of the retention basin [16]. The calculation result showed the need for 1). the addition of pumping machines with the capacity of 1 m^3/sec., thus, the capacity became 5 m^3/sec. and 2). the addition of the long-storage of Siwatu river with dimension of b. 8.00 m h.2.00 p.500 m p.500 m, thus the total volume became 45000 m^3. The pumping operation remained at the water elevation of +1.400.

4.4 Optimization Recapitulation

Below are the results of optimization recapitulation of Tegalsari retention basin, Tegal City.

Table 3. Results of Optimization Recapitulation.

Q Plan	Optimization Plan		
	Type 1	**Type 2**	**Type 3**
Q.10	The addition of pump capacity of 3 m^3/sec. thus, it became 7 m^3/sec.	Addition of a long-storage with the dimension of (8x2,50x500) m	1. Addition of pumping machines with the capacity of 1 m^3/sec, therefore, the capacity became 5 m^3/sec. and, 2. Addition of the long-storage with the dimension of (8x2,00x500) m

5. Conclusion and Suggestion

Results of the analysis and discussion showed that 1) based on the hydraulic study, the existing channel of Siwatu drainage system could not accommodate flood discharge capacity, 2) the catchment volume of Tegalsari retention basin of 37000 m^3 was smaller than the volume of the estimated discharge of Q10: 46188 m^3. Therefore, the additional volume of minimum 9188 m^3 was required, 3) Although the 4 m^3/sec. pumping machines were operated, inundation still happened. This inundation happened in the area with the height under +1.700 and lasted for 3 – 4 hours for Q10 years with the height of 20 to 50 cm, and 4) the optimization of Tegalsari retention basin, Tegal city for Q.10 years could be made by the addition of 3 m^3/sec. pumping machines, long-storage basin with dimension of 8 x 2.50 x 500 m and, the combination of the addition of 1 m^3/sec. pumping machine as well as the addition of long-storage basin with the dimension of 8 x 2.00 x 500 m.

The following are suggestions made based on the results of discussions related to efforts to resolve flooding and inundation problems in Tegalsari retention basin service area, Tegal City: (1) for a short term management, flooding and waterlogging problems can be solved by increasing the channel capacity through dredging and normalizing Siwatu river, controlling buildings above the river, operating 4 pumps simultaneously, and increasing the pumping machines working hours, (2) for a medium-term management, Siwatu River needs to be optimized to be a long-storage, and (3) for a long-term management, drainage system of Siwatu, Tegal City needs to be better organized to overcome the existing problems of flooding and inundation.

6. Acknowledgement

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